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COMPENSATED INFRARED ABSORPTION
SENSOR FOR CARBON DIOXIDE
AND OTHER INFRARED ABSORBING GASES

RELATED PATENT APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/439,319, filed January 10, 2003 and entitled "COMPENSATED INFRARED ABSORPTION CARBON

5   DIOXIDE SENSOR".

TECHNICAL FIELD OF THE INVENTION

This invention relates to detecting the presence of gas in a gas mixture, and more particularly to an

10   infrared absorption sensor for measurement of the content of carbon dioxide (or other infrared absorbing gas) in a gas mixture.

GOVERNMENT RIGHTS CLAUSE

15   The U.S. Government has a paid-up license in this invention and the right in certain circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Contract No. DE-FC21-96MC33033 for the U.S. Department of Energy.

BACKGROUND OF THE INVENTION

　　　　Most gases and vapors exhibit well defined optical
spectral absorption bands, in which the transmission of
optical energy is absorbed. Carbon dioxide (CO_2) has

5   several absorption bands in the infrared optical range.
In particular, a predominant absorption band occurs at a
wavelength of 4.26 micrometers. This absorption band is
relatively sharply defined within a wavelength range of
about 4.26 plus or minus 0.2 micrometers. Infrared

10   radiation transmitted through CO_2 gas at a wavelength of
4.26 micrometers is strongly attenuated.

　　　　The absorption of infrared radiation in a gas occurs
at the atomic and molecular level. In the case of CO_2,
the polyatomic molecular structure determines the photon

15   excitation modes and energy exchange rates, and hence,
the wavelengths at which optical energy absorption
occurs. Because this absorption effect occurs at the
molecular level, the absorption of infrared radiation
along a given transmission path depends on the number of

20   molecules present. That is, the amount of absorption at
4.26 micrometers is directly proportional to the
molecular fraction of CO_2 present in a gas mixture.
Additionally, because pressure and temperature affect the
density of the gas, the absorption is also dependent on

25   the pressure and temperature at which the infrared
absorption measurements are made.

　　　　This selective optical absorption phenomena has
application as a method for determining the presence and
amount of CO_2 in samples of gas mixtures. For example, a

30   basic CO_2 sensing technique in common use employs an
infrared radiation source (typically an incandescent

lamp) and an infrared detector (typically a semiconductor photodiode) in a closed chamber in which gas samples are introduced for testing. A narrowband interference filter is used as the optical window of the photodiode detector

5 to make it selective only to the 4.26 micrometer absorbing wavelength. For a given optical path length in the test chamber, the photodetector output can be calibrated using gas mixtures having a known CO_2 gas concentration to provide a useful instrument for sensing

10 CO_2 in a variety of gas mixtures. The basic sensitivity of this arrangement depends on the sharpness of the interference filter so as to minimize the amount of infrared radiation not related to CO_2 absorption reaching the detector, the optical path length containing the CO_2

15 molecules, the luminance stability of the infrared radiation source, and the stability of the detection response of the photodiode detector. Other factors that can affect the sensitivity and calibration accuracy of the method include possible turbulent flow in the gas

20 sample passing through the test chamber, aging of the infrared radiation source and detector, and contamination accumulation on the source and detector optical windows.

The effects of turbulent flow can be minimized, and reliable measurements of gas pressure and temperature can

25 be provided, by proper test chamber design. Other sources of error, such as aging effects on the source intensity and detector sensitivity and non-uniform contamination on the optical windows can be minimized by using the 4.26 micrometer wavelength to sense the

30 absorption of CO_2 in the presence of the various error-causing factors and also sensing the infrared intensity

incident on the detector at a nearby wavelength, such as at 3.9 micrometers, at which no CO_2 absorption occurs. Then, by normalizing the CO_2 absorption response to the non-absorbing response, the errors associated with all

5 factors other than the molecular absorption of CO_2 can be compensated in the sensor output reading. An example of an error-compensated CO_2 sensor is described in U.S. Patent No. 5,646,729, entitled "Single Channel Gas Concentration Measurement Method and Apparatus Using a

10 Short-Resonator Fabry-Perot Interferometer", issued in 1997 to Koskinen, et al.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 illustrates a first embodiment of a sensor in accordance with the invention, having a semicircular arrangement of filters and choppers.

FIGURE 2 illustrates a second embodiment of a sensor in accordance with the invention, having an annular arrangement of filters and choppers.

DETAILED DESCRIPTION OF THE INVENTION

        FIGUREs 1 and 2 illustrate two embodiments of a
compensated infrared CO_2 sensor in accordance with the
invention. Both embodiments have two optical paths, but
5   only a single infrared radiation source 102, 202 and a
single infrared radiation detector 103, 203. Both
embodiments use a pair of fixed optical interference
filters 106a/106b, 206a/206b in combination with an
optical chopper 108, 208 to achieve separate and
10 independent measurements at 4.26 micrometers and at 3.9
micrometers. By normalizing the 4.26 micrometer
absorption measurement with the 3.9 micrometer
measurement, aging effects in the infrared source 102 and
in the detector 103, and to some extent, the effects of
15 contamination of the optical windows, are compensated.

        For purposes of this description, the 4.26
micrometer wavelength is referred to as the "gas
attenuating" wavelength. The 3.9 micrometer wavelength
is referred to as the "reference" wavelength. It is
20 possible that other wavelengths in the neighborhood of
3.9 micrometers could be used. It is expected that a
range of 3.9 micrometers plus or minus 0.1 micrometers
could be used. Wavelengths outside that range are
undesirable because of interference with the 4.26
25 micrometer wavelength.

        FIGURE 1 illustrates a first embodiment of a
compensated infrared CO_2 sensor 100 in accordance with
the invention. The sensor chamber 101 has an infrared
radiation source 102 at one end and an infrared detector
30 103 at the other. In the example of this embodiment, the
radiation source 102 is an incandescent lamp, and the

infrared detector 103 is a photodiode. A gas inlet 101a permits chamber 101 to receive gas containing CO_2 and a gas outlet 101b is used to exhaust the gas.

Chamber 101 is generally tubular in shape, and in the embodiment of this description has a circular cross sectional area. The interior elements, namely collimator lens 105, filters 106a and 106b, chopper 107, and focusing lens 108 can be made circular in shape to generally conform to the inner diameter of chamber 101. In other embodiments, chamber 101 could have a cross sectional geometry other than cylindrical, such as a rectangular cross section with the interior elements modified in shape accordingly.

Collimator lens 105 collimates the infrared radiation from source 102 and focusing lens 108 focuses the radiation on detector 103. Lenses 105 and 108 are typically sapphire or germanium lenses.

In the example of this description, where chamber 101 is cylindrical, filters 106a and 106b each have a semicircular geometry. One filter filters a first half of the cross-section of the collimated radiation along the length of chamber 101 and the other filter filters the other half of the collimated radiation cross-section. As stated above, one filter is selective to 3.9 micrometer wavelength and the other is selective to 4.26 micrometer wavelength. The effect of filters 106a and 106b is to split the radiation path in half, so that one half comprises 4.26 micrometer wavelength radiation and the other half comprises 3.9 micrometer wavelength radiation.

Choppers 107a and 107b chop the radiation passing through the filters 106a and 106b, respectively. The geometry of choppers 107a and 107b conforms to the geometry of filters 106a and 106b, such that each chopper

5   has a semicircular geometry. Choppers 107a and 107b act as alternating shutters to block and pass the radiation transmitted through the filters 106a and 106b. They operate sequentially such that detector 103 sequentially and periodically receives a reference signal from filter

10 107a and a CO_2-attenuated signal from filter 107b (or vice versa).

Choppers 107a and 107b are implemented with liquid crystal devices (LCDs), and perhaps most conveniently as a two-section liquid crystal chopper. For example, an

15 LCD array could be used such that its top portion is used to chop the radiation from filter 106a and its bottom portion is used to chop the radiation from filter 106b. The two portions are thus independently operable.

The use of liquid crystal choppers eliminates the

20 need for a mechanical rotating disk chopper. Various commercially available liquid crystal compounds, such as Lixon 5005 or Lixon 5018 manufactured by the Chisso Company, Ltd., combined with appropriate infrared optical polarizer components may be used to form electrically

25 driven LCD light modulator devices adaptable for use as choppers 107a and 107b, provided that they are suitable for transmitting and blocking the particular infrared radiation wavelengths of interest.

Conventional electronic circuitry and processing

30 devices (not shown) may be used to control choppers 107a and 107b and to normalize the 4.26 micrometer signal by

the 3.9 micrometer signal. The attenuation of the signal through chopper 107b depends on the amount of CO_2 present in the optical path within chamber 101.

FIGURE 2 illustrates a second embodiment of a

5 compensated infrared CO_2 sensor 200 in accordance with the invention. Like sensor 101, its sensor chamber 201 has a single infrared radiation source 202 and a single infrared detector 203.

Chamber 201, and its inlet 201a and outlet 201b are

10 essentially the same as those of sensor 101. Likewise, collimator lens 205 and focusing lens 208 are the same.

Filter 206a has an annular geometry and filter 206b has a circular geometry. The annular geometry of filter 206b generally forms a collar extending into the inner

15 diameter of chamber 201. The circular geometry of filter 206b fills the middle of the ring formed by filter 206a. As a result of the configuration of filters 206a and 206b, filter 206a filters an outer ring of the collimated radiation along the length of chamber 201 and filter 206b

20 filters an inner beam of the radiation. One filter is selective to a 3.9 micrometer wavelength and the other is selective to 4.26 micrometer wavelength.

Choppers 207a and 207b chop the radiation transmitted from filters 206a and 206b, respectively.

25 The geometry of choppers 207a and 207b conforms to the geometry of filters 206a and 206b, such that chopper 207b is annular and chopper 206b is circular.

In other words, the geometry of the filters and chopper of the embodiment of FIGURE 2 is "annular" in the

30 sense that an inner portion of the filters and the chopper operate on an inner portion of the beam of

infrared radiation and an outer portion of the filters
and the chopper operate on an outer portion of the beam
of infrared radiation. If chamber 201 were to have a
rectangular cross section rather than circular, the same
5   geometry would apply such that an inner rectangular area
(rather than an inner circular area) would be filtered
and chopped differently from an outer rectangular area.

In contrast, the geometry of the filters and chopper
of the embodiment of FIGURE 2 is "split", in the sense
10   that a first portion of the filters and the chopper
operate on a first side of the beam of infrared radiation
and a second portion of the filters and the chopper
operate on a second of the beam of infrared radiation.
The split geometry could be two halves of a circle or two
15   sides of a rectangular, depending on the inner cross
sectional geometry of chamber 101.

The size of both embodiments described above can be
quite small. The infrared sources 102 and 202 and the
detectors 103 and 203 can be "grain of wheat" sized
20   devices. The overall dimensions of sensors 100 and 200,
assuming they are cylindrical in shape, could be as small
as 1/2 inch in diameter and 1 inch in length.

In both embodiments described above, the normalized
output signal from the sensor is independent of any
25   changes in the common infrared source and photodiode
detector used in the alternating measurements. Also,
because the lenses and filters are relatively small,
their surfaces will tend to accumulate uniformly
distributed contamination on their surfaces.

30   In the above-described embodiments, each pair of
filters (106a/106b and 206a/206b) intercepts

approximately half of the radiation from the associated
radiation source.   In other words, their surface areas
are equal.   Also, the filters are placed adjacent each
other so that they each intercept a portion of the

5   radiation within chamber 101 or 201 at the same distance
from the radiation source 102.   In the embodiments of
FIGUREs 1 and 2, they are in the same plane across the
cross sectional area of the chamber. This is the simplest
and most direct approach to normalization of the signal.

10 However, filters having different surface area sizes and
placements may also be used.

    Although the description above is directed to CO2
sensing, especially in natural gas, the same concepts
could be applied to detect other gases that absorb

15 infrared radiation and other gas mixtures.   For example,
the presence of water vapor or gaseous ammonia could be
detected using their appropriate infrared absorption
wavelengths.